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Synthesis of SMC algorithms applied to wind generator

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ABSTRACT

The use of the classical (SMC) applied to control of stator's powers of DFIG, gives the problem of chattering, therefore to avoid this phenomenon a robust algorithm (STSMC) is applied. This paper presents a comparison of conventional SMC with the proposed strategy of STSMC algorithm. The results are obtained using MATLAB and demonstrate stability and robustness of this algorithm.

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1. INTRODUCTION

Energy consumption has increased over the last decades considerably due to massive industrialization. A good alternative is to use renewable energies, which offer the possibility of producing electricity properly [1]. Among the renewable energies we find the wind turbine, which is becoming competitive in terms of production costs. It is reducing the emissions of greenhouse gases. Today, variable speed wind turbines based on (DFIG) offers many benefits, such as their efficient power density, the dimensioning of the converter on the rotor side is reduced to 30% of the nominal power of the machine [2], [3]. To have maximum wind power we use variable speed wind turbines [4], so to achieve this goal, the peak turbine speed ratio must be maintained at its optimum value despite the variation in wind speed [5], [6]. To solve the problem of tracking the maximum power point, different control techniques have been used, among them conventional (SMC). This controller offers some advantages: relative simplicity of implementation, robustness and external disturbances [7].

SMC is a robust control method [8], which guarantees the performance of the dynamic system by rejecting any disturbance acting on it. Despite the simplicity of its conception, the discontinuity of this command gives rise to the phenomenon of chattering. Several researchers have proposed solutions to avoid this phenomenon and guaranteed stability in steady state. [9], [10].

This paper presents a robust super-twisting sliding mode control of doubly fed induction generator (DFIG) based wind turbines. The simulation results showed a good STSMC control compared to the SMC algorithm. The rest of this article is organized as follows: Section 2 presents the wind turbine and DFIG modeling. The Section 3 describes the fundamental formulation of the proposed STSMC applied to the power

based on DFIG. Section 4 presents the simulation results to demonstrate the performance of the proposed control scheme. At the end, conclusion is given in Section 5.

2. MATERIAL AND METHOD
2.1. The generator mode1
Block diagram of a wind turbine based on DFIG is given in figure 1. The model contains of a wind turbine, DFIG, converters, and a gearbox. The stator is connected to the network via a three-phase transformer and the rotor via another three-phase current source [11].

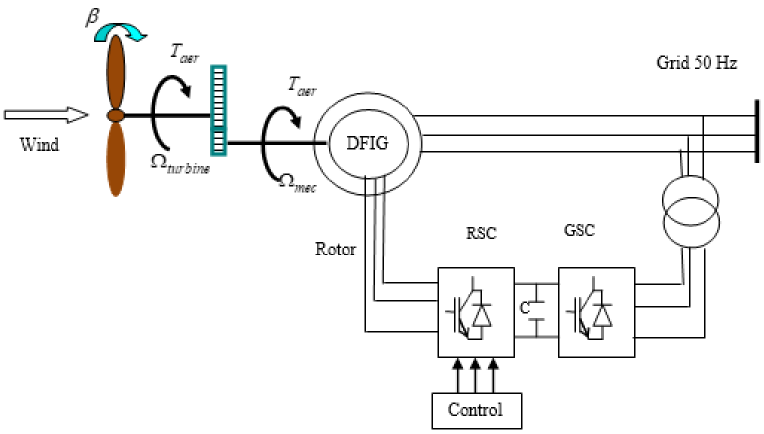

Figure 1. Scheme diagram of DFIG-based wind turbine

2.2. Turbine modeling
The expression of the aerodynamic power is presented by the (1) [12]:

$$P_t = \frac{1}{2} C_p(\lambda)\ \rho \pi R^2 v^3 \quad (1)$$

The $C_P(\lambda)$ is power coefficient, is a nonlinear function of the relative speed ratio $\lambda = \frac{\Omega R}{v}$, with v is wind speed (m/s), $\rho$is the air density (kg/m3), R is the radius of the rotor blades (m), Ω is the angular frequency of the blades the mechanical rotation speed and (rad/s).

The power coefficient of the wind turbine is shown in the Figure 2. This figure indicates that the tip speed ratio is kept equal toλ_{opt}., the$C_P(\lambda)$ capture the maximum power [12], [13].

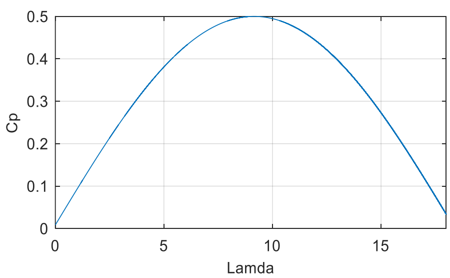

Figure 2. Power coefficient of wind turbine

2.3. Modeling of the DFIG
The active and reactive stator and rotor powers are represented as (6), (7) [14]:

$$\begin{cases} P_s = v_{ds}i_{ds} + v_{qs}i_{qs} \\ Q_s = v_{qs}i_{ds} - v_{ds}i_{qs} \end{cases} \tag{6}$$

$$\begin{cases} P_r = v_{dr}i_{dr} + v_{qr}i_{qr} \\ Q_r = v_{qr}i_{dr} - v_{dr}i_{qr} \end{cases} \tag{7}$$

the electromagnetic torque is given by (8):

$$T_{em} = p(\varphi_{ds}i_{qs} - \varphi_{qs}i_{ds}) \tag{8}$$

3. DFIG CONTROL STRATEGY

3.1. Vector control of the active and reactive powers

To independently control the active and reactive stator powers, we use the vector control which makes the DFIG similar to a DC motor

$$\varphi_s = \varphi_{ds} \quad \Rightarrow \quad \varphi_{qs} = 0 \tag{9}$$

The torque is simplified as shown below:

$$\begin{cases} \varphi_{ds} = L_s i_{ds} + M i_{dr} \\ 0 = L_s i_{qs} + M i_{qr} \end{cases} \tag{10}$$

Neglecting the stator resistance gives the (12)

$$\begin{cases} v_{ds} = 0 \\ v_{qs} = V_s \end{cases} \tag{11}$$

The equations (12) are obtained when replacing the rotor flux (5) in (3), the rotor voltages are:

$$\begin{cases} v_{dr} = \sigma L_r \frac{di_{dr}}{dt} + R_r i_{dr} - \sigma L_r \omega_r i_{qr} + \frac{M}{L_s}\frac{d\varphi_{ds}}{dt} \\ v_{qr} = \sigma L_r \frac{di_{qr}}{dt} + R_r i_{qr} + \sigma L_r \omega_r i_{dr} + \frac{M}{L_s}\omega_r \varphi_{ds} \end{cases} \tag{12}$$

where: $\omega_r = \omega_s - \omega = g\omega_s$is the slip frequency, g is the slip range and $\sigma = 1 - \frac{M^2}{L_s L_r}$is the leakage coefficient. The rotor voltages can be rewritten as follows (13):

$$\begin{cases} v_{dr} = \sigma L_r \frac{di_{dr}}{dt} + R_r i_{dr} + f_{em,d} \\ v_{qr} = \sigma L_r \frac{di_{qr}}{dt} + R_r i_{qr} + f_{em,q} \end{cases} \tag{13}$$

with $f_{em,d}$and$f_{em,q}$ are the coupling terms (14):

$$\begin{cases} f_{em,d} = -\sigma L_r \omega_r i_{qr} + \frac{M}{L_s} \cdot \frac{d\varphi_{ds}}{dt} \\ f_{em,q} = -\sigma L_r \omega_r i_{dr} + \frac{M}{L_s} \cdot \omega_r \cdot \varphi_{ds} \end{cases} \tag{14}$$

The stator active and reactive powers are given by the (15):

$$\begin{cases} P_s = -V_s \cdot \frac{M}{L_s} i_{rq} \\ Q_s = -V_s \cdot \frac{M}{L_s}\left(i_{rd} - \frac{\varphi_s}{M}\right) \end{cases} \tag{15}$$

The rotor current along the d and q axes is represented by (16) and (17)

$$i_{rd} = \frac{1}{\sigma L_r}\left(v_{dr} - R_r i_{rd} + \sigma L_r \omega_r i_{rq}\right) \quad (16)$$

$$i_{rq} = \left(v_{rq} - R_r i_{rq} - \sigma L_r \omega_r i_{rd} - g\frac{M}{L_s} v_s\right)\frac{1}{\sigma L_r} \quad (17)$$

4. WIND TURBINE CONTROL BASED ON DFIG

4.1. SMC control

Sliding mode control is a mode of operation of variable structure control systems (VSCS). It is robust in view of the insensitivity to parametric variations and to external disturbances.

4.2. Choice of switching surface

The sliding surface given by Slotine is defined as (18) [15]:

$$S(X) = (\frac{\partial}{\partial t} + \lambda_X)^{r-1} e(X) \quad (18)$$

where: $e(X)$is the error tracking; r: system order and λ_χ is a positive coefficient.

4.3. Condition of convergence

The existence of SMC can be proved by using a Lyapunov function (19).

$$V(X) = \frac{1}{2} S^2(X) \quad (19)$$

The derivative is given by (20):

$$\dot{V}(X) = S(X)\dot{S}(X) \quad (20)$$

To make the Lyapunov function derivative of (19) the negative definite, we have to find adequate control input. To ensure stability, the control is designed as follows (21) [16], [17]:

$$S(X)\dot{S}(X) < 0 \quad (21)$$

The sliding mode control algorithm consists of two terms: a discontinuous term which ensures the stability of the system and an equivalent term which brings back the state of the system on the sliding surface [18], [19]:

The control algorithm is defined by (22):

$$u = u_{eq} + u_n \quad (22)$$

where:

$$u_n = Ksign\big(S(X)\big) \quad (23)$$

5. SUPER-TWISTING SLIDING MODE CONTROL DESIGN

To remedy the problem of chattering during the implementation of the control sliding mode, we use other more efficient techniques called super-twisting ST algorithm [20], [21].

The control u_{ST}control contains the sum of two terms (24) [22], [23]:

$$\begin{cases} u_{ST} = u_1 + u_2 \\ \dot{u}_1 = -\lambda sign(S) \\ u_2 = -\alpha |s|^{\frac{1}{2}} sign(S) \end{cases} \quad (24)$$

where:

$$\alpha > 0, \lambda > 0$$

The convergence condition is given by (25) [24] [25]:

$$\begin{cases} \lambda > \dfrac{C}{K_m} \\ \alpha^2 \geq \dfrac{4CK_M(\lambda + C)}{{K_m}^3(\lambda - C)} \end{cases} \tag{25}$$

where C,K_M,K_m are theconstants values of super-twisting sliding mode controller.

Figure 3 show the state trajectory of the $S$and $\dot{S}$ phase plane.

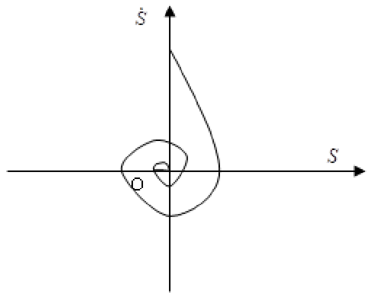

Figure 3. Trajectory phase plane of ST algorithm

5.1. Super-Twisting sliding mode control design

The errors of the powers are given by (26):

$$\begin{cases} S(P_s) = e_{PS} = P_s * - P_s \\ S(Q_s) = e_{QS} = {Q_s}^* - Q_s \end{cases} \tag{26}$$

where ${P_s}^*$ and ${Q_s}^*$ are the reference values of the statoractive and reactive powers.

Then we will have:

$$\dot{S}(P_s) = \dot{P}_s * - \dot{P}_s \tag{27}$$

$$\dot{S}(Q_S) = \dot{Q}_S * - \dot{Q}_S \tag{28}$$

Substituting (15) and (17) into (27) leads to:

$$\dot{S}(P_s) = \dot{P}_s{}^* + \left(v_{rq} - R_r i_{rq} - \sigma L_r \omega_r i_{rd} - g \frac{M}{L_s} V_s\right) \frac{1}{\sigma L_r} \tag{29}$$

When the state of the system is on the surface of sliding, then:

$$S(P_s) = 0; \dot{S}(P_s) = 0; v^n{}_{rq} = 0$$

so, the equivalent command is given by:

$$v^{eq}{}_{rq} = R_r i_{rq} + \sigma L_r \omega_r i_{dr} + g \frac{MV_s}{L_s} + \ddot{\imath}_{rq} \cdot \frac{V_s M}{L_s} \tag{30}$$

Therefore:

$$v^n{}_{rq} = -\lambda |S|^\rho sign(S) - \int \alpha\, sign(S) \tag{31}$$

The stator reactive power of the DFIG is represented by substituting (15) and (16) into (28) leads to:

$$\dot{S}(Q_s) = \dot{Q}_s^{\ *} + V_s \frac{M}{L_s \sigma L_r}\left(v_{rd} - R_r i_{rd} + \sigma L_r \omega_r i_{rq}\right) \tag{32}$$

when:

$$S(P_S) = 0; \dot{S}(P_S) = 0; v^n{}_{rd} = 0$$

The equivalent command is $v^{eq}{}_{rd}$ is defined as:

$$v^{eq}{}_{rd} = -\frac{\sigma L_r}{M}\left(\lambda \ddot{\varphi}_s - \lambda M \ddot{\imath}_{rd} - \dot{\varphi}_s - \frac{M R_r}{\sigma L_r} i_{rd} + M \omega_r i_{rq}\right) \tag{33}$$

hence:

$$v^n rd = -\lambda |S|^{\rho} sign(S) - \int \alpha \, sign(S) \tag{34}$$

Figure 4 shown the block diagram of the DFIG controlled by the second order sliding mode which uses the super-twisting algorithm.

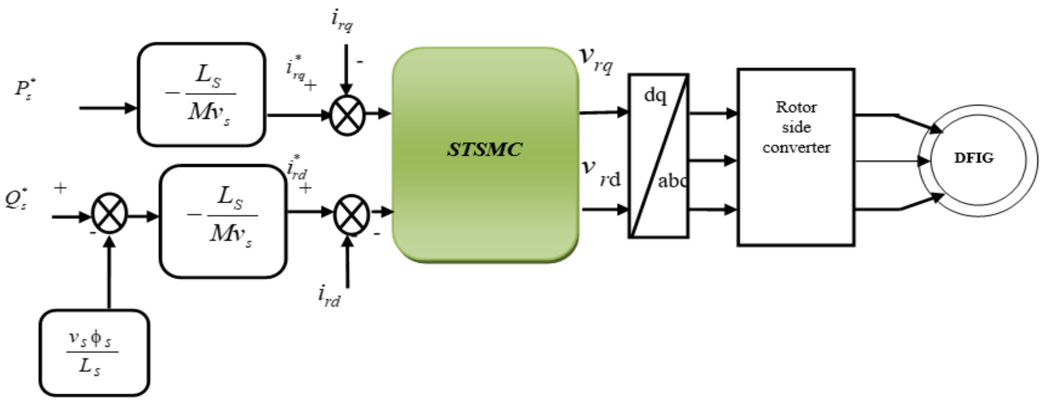

Figure 4. Structure of STSM control

6. RESULTS AND DISCUSSION

The block diagram (Figure 4) is validated by a simulation using the parameters indicated in the appendix. A comparison between the two controllers STSMC and classic SMC is applied to a DFIG. This comparison shows that the STSMC is more efficient and robust than SMC. Figure 5 illustrates the reference of the active and reactive power.

Table 1. DFIG parameters nominal

7.5 *KW*	400/690V	50 *Hz*
P = 2	R_S = 0.455 Ω	R_r = 0.62 Ω
M = 0.078 *H*	L_S = 0.084 *H*	L_r = 0.081 *H*

Table 2. Parameters turbine

Diameter = 14 *m*
Gearbox = 28
Number of blades = 3

Table 3. (DFIG+Turbine)

$J = 50\ Kg \cdot m^2$
$f = 0.071\ N \cdot m \cdot s/rd$

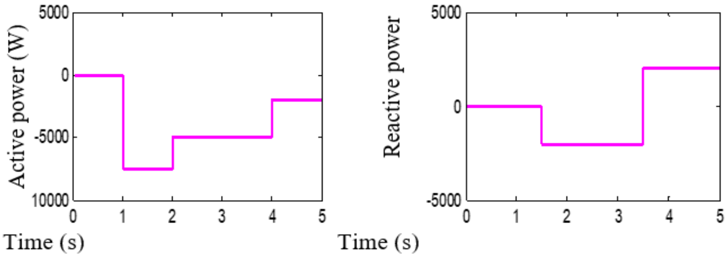

Figure 5. Reference of stator's powers

As clearly shown in Figure 6 and Figure 7, the super-twisting sliding mode control-based system has almost similar tracking performance as the conventional sliding mode control-based system of DFIG stator's powers. It is found that classical sliding mode control-based system suffers from chattering effect; whereas STSMC based system is free from this phenomenon. Figure 8 and Figure 9 illustrate the direct and quadrature rotor current. Figure 10 shows the dynamic responses of the electromagnetic torque. The control by the super-twisting sliding mode of the DFIG gives a good poursuit and is better than SMC controller.

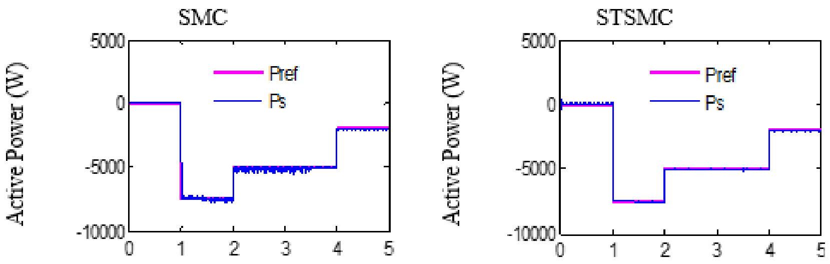

Figure 6. Active power tracking performance

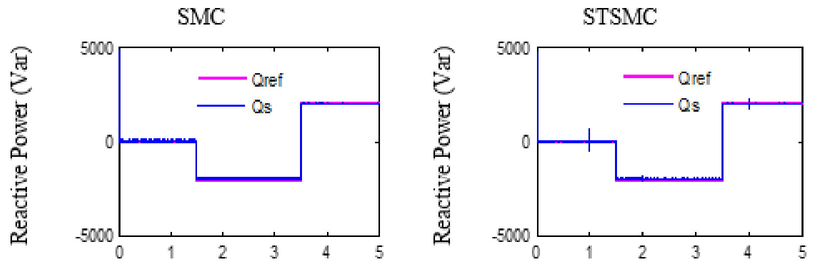

Figure 7. Reactive power tracking performance

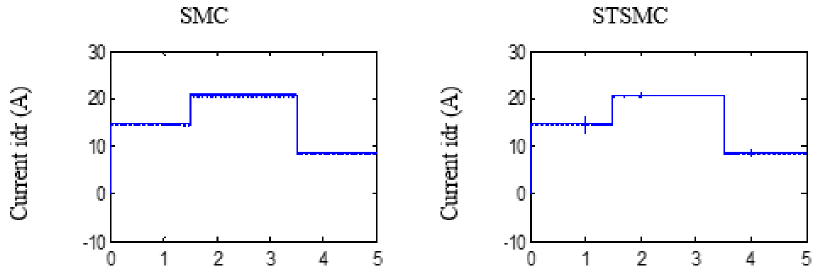

Figure 8. Current idr

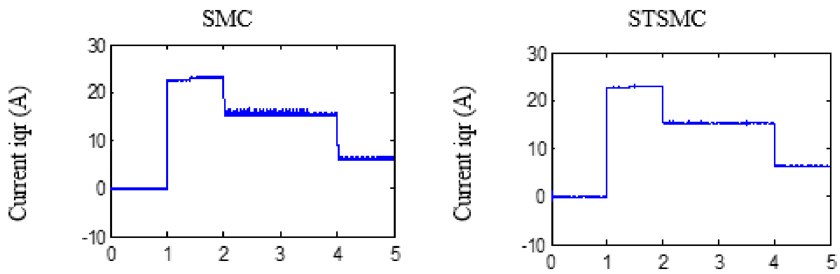

Figure 9. Current iqr

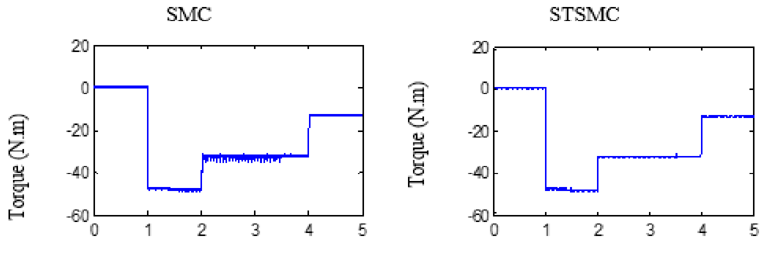

Figure 10. Torque

7. CONCLUSION

The application of the STSMC algorithm on a DFIG has been shown in this article. The STSMC algorithm is used for stator’s powers control. The proposed approach gives good performance (good tracking, disturbance rejection and minimizes the chattering phenomenon).

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